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Sharp and blunt force trauma concealment by thermal alteration in homicides: an in-vitro experiment for methodology and protocol development in forensic anthropological analysis of burnt bones.

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Highlights:

- Non-human bones were subject to sharp and blunt force trauma, followed by burning
- Sharp and blunt force trauma signature were not entirely masked by heat exposure
- In these burnt specimens, it was possible to trace the origin of the trauma impact
- Emphasis is placed on future standardization of fracture experimentation in burnt bone.
- Promotes the use of anthropologists in the recovery of human remains at fire scenes

Abstract

Burning of human remains is one method used by perpetrators to conceal fatal trauma and expert opinions regarding the degree of skeletal evidence concealment are often disparate. This experiment aimed to reduce this incongruence in forensic anthropological interpretation of burned human remains and implicitly contribute to the development of research methodologies sufficiently robust to withstand forensic scrutiny in the courtroom. We have tested the influence of thermal alteration on pre-existing sharp and blunt trauma on twenty juvenile sheep radii in the laboratory using an automated impact testing system and an electric furnace. The testing conditions simulated a worst-case scenario where remains with pre-existing sharp or blunt trauma were exposed to burning with an intentional vehicular fire scenario in mind. All impact parameters as well as the burning conditions were based on those most commonly encountered in forensic cases and maintained constant throughout the experiment. The results have shown that signatures associated with sharp and blunt force trauma were not masked by heat exposure and highlights the potential for future standardization of fracture analysis in burned bone. Our results further emphasize the recommendation given by other experts on handling, processing and recording burned remains at the crime scene and mortuary.

Keywords: forensic anthropology, human remains, burning, sharp force trauma, blunt force trauma, homicide.

1. Introduction

Deaths from sharp and blunt force trauma are common in homicide cases [1-5], particularly in countries where civilian use of firearms is strictly regulated. In England and Wales for instance, 2011-12 homicide data shows that out of 550 homicides, 200 resulted from sharp instruments and more than 100 from blunt trauma [6]. Homicides, whether by sharp, blunt or other type of trauma, are often concealed through burning [7]. In such circumstances, where expertise in burn patterns and differential bone fracture propagation is required, the presence of the forensic anthropologist is advisable [8-11]. Currently, this expertise mainly relies on experimental research investigating perimortem trauma in the absence of thermal alteration or vice versa and forensic casework experience.

In the literature, cremated bone has been examined macroscopically, especially with regard to methods for biological profile estimation [12,13]. Microscopically, bone structure and compositional changes have also been investigated at length [14,15] using specialized analytical techniques such as X-ray diffraction and/or X-ray spectroscopy [16,17], Scanning Electron Microscopy [18,19], Transmission Electron Microscopy [20] and Fourier Transform Infrared [21,22]. In contrast, investigations of full-body burn patterns [23-25] and effects of flesh combustibility [26,27] are scarce, with a limited number of studies analysing remains from crematoria [28,29]; these aspects have been addressed secondarily to, for instance, analysis and weighing of cremated remains for identification [30,31]. With respect to mechanical trauma, blunt trauma research has been extensive, with studies from both clinical and forensic perspectives. Although these mainly focus on head trauma [32,33] and associated computerized models [34,35], they also include analysis of fractures associated with child abuse [36,37], fracture toughness in long bones [38] and autopsy case reports of various accident types [39,40]. Similarly, sharp force trauma has also been thoroughly investigated, with studies addressing stabbing events [41,42], cut marks, weapon edge striations analysis and metal residues at impact sites using microscopic techniques [43,45] and knife blade [46] and screwdriver tip morphology [47] at macroscopic level. However, experimental research combining both perimortem trauma and thermal alteration is scarce [11,28,48-50], the majority with inadequately controlled testing environments and unevenly distributed sample sizes and demographics.

In light of the current literature, we hypothesized that 'fresh' bone trauma morphology and any associated fracturing, although exacerbated by heat, will still be distinguishable from damage produced by thermal alteration due to differential failure mechanism of bone. Juvenile sheep radii were used in the simulation of a closed-compartment fire [18,50,51] in which calcined human remains recovered presented either sharp or blunt trauma in addition to various types of defects and fractures due to burning. The current sharp trauma experiment simulated a typical cutting action impact produced by a large knife; whilst the blunt trauma experiment simulated a baseball bat impact [33,42]. The methodology was repeatable whereby equipment which allowed proper regulation of the scenario was utilized. Biomechanically, control of the nature of impact during experimentation is of high importance for an understanding of how and why bone behaves in a particular manner during loading.

The principal objectives of this controlled experiment are: to demonstrate that field experiments can be replicated in a realistic manner in the laboratory and that the variation in the observed thermal defects can be reduced to factors which are pertinent to the variables being tested rather than to factors which cannot be fully controlled in a field experiment. Hence, the main aim is to resolve discrepancies amongst experimental approaches which deter adequate comparison of data sets and which are the cause for current divergence in expert opinion by investigating which types of heat fractures occur and whether this is dependent on the presence of mechanical trauma.. This approach also seeks to promote future drafting of experimental protocols sufficiently robust to withstand forensic scrutiny, thereby solidifying forensic anthropological expert opinion in the courtroom.

2. Materials and Methods

Samples

Twenty fresh juvenile sheep radii under three years of age (verified by the degree of epiphyseal fusion [52] ~~[73])~~ were purchased from a local abattoir (the sheep were slaughtered on the day the purchase was made). The samples were allocated as follows: two samples for determining optimal experimental conditions, 14 for the applied mechanical trauma and four as controls; the latter group were thermally altered intact and in the absence of previously applied trauma. Specimens were kept in a laboratory freezer and subsequently removed and refrigerated at 4°C for two days for gradual defrosting in advance of the experiment. After defrosting, larger muscle layers were removed using a dissection scalpel and each specimen was photographed and measured.

Sheep was preferred because its frequent use in the literature allowed comparison with other studies [53,54]. Defleshing was carried out because fat, muscle and skin act as fuel themselves [26] and will affect the temperature at, which the bone is burnt. Since their proportions can vary between individuals, removing the soft tissue ensured greater temperature uniformity across all specimens.

Mechanical Trauma

Trauma was dynamically applied using an IMATEK Impact Testing System (Imatek® Ltd, Old Knebworth, Herts**,** SG3 6QJ, UK) equipped with a sensor to control and record load, time, energy dissipation and an experimental chamber within which the test rig and samples were mounted. Fourteen samples were used, seven for the sharp trauma (SFT 1-7) and seven for the blunt trauma experiments (BFT 1-7). The specimens were wrapped in commercially available cling film to ensure stability during impact and prevent the loss of bone fragments (if produced).

The sharp trauma scenario replicated a cutting action with a large knife, using a striker measuring 2.2x0.01 cm (Fig.1) at a velocity of 4.0 m/s and a total impact mass of 3.703 kg. This corresponded to impact energy of approximately 28 J and a peak force of 3.2-4.0 kN. The blunt trauma experiment simulated a baseball bat impact using a 15 cm long and cylindrical impactor (Fig.2) at a velocity of 6.0 m/s and total impact mass of 4.102 kg; corresponding to approximately 84 J and a peak force of 5.6-7.7 kN.

Each specimen was placed onto three non-deformable sponges, with each epiphysis further secured with plastic tape (Figs.3,4). This ensured that the impactor would always come into contact with the midsection of the anterior surface of the bone shaft, perpendicularly to the long axis of the bone. The purpose was to isolate impact forces to compression and tension and maintain impact angle constant to reduce variability in the resulting defects [55-57]. The correlation between impact generated by the testing system and impact generated by a manually-handled object is as follows: the impact velocity originates from the generated momentum during the hitting action whilst the impact mass is a combination of the actual mass of the object and that originating from the body of the attacker; together, these generate the impact force to which the sample is subjected.

Thermal Alteration

The thermal alteration experimental component reproduced a closed-compartment fire where skeletal remains with perimortem trauma were expected to become fully calcined, fractured and highly fragile [50,51]. A CARBOLITE CWF 110 electric furnace (Carbolite® Gero Ltd., Parsons Lane, Hope Valley, S33 6RB, UK) was used, equipped with adjustable temperature and duration controls and fitted with a peep hole for visualization of specimens during cremation. Each burning or cremation session followed the same set-up whereby a limestone slab was placed inside the furnace on top of which two ceramic tiles were arranged; the purpose of the limestone slab was to raise the specimens to a level at which maximal heat exposure could be achieved whilst the ceramic tiles were used to extend the surface area for placement of more than two specimens at a time (Fig.5). The controls (CS 1-4) were burned and analysed first to establish a basis of heat defects and fracture patterns for comparison with those to be subsequently encountered in the trauma samples.

The epiphyses of the bone samples subjected to trauma were removed using an automated metallurgical saw (Struers®, Accutom 2) to allow placement of more than two specimens within the furnace, thus simulating cremation of a set of remains. To imitate the insulation effects of soft tissues, specimens were placed inside the furnace at room temperature which was set to increase at an average of 12-14°C/minute to a peak temperature of 820°C (i.e. duration of room-to-peak temperature increase was approximately 58 minutes). The furnace was then turned off and cooled back to room temperature prior to sample removal to prevent fracture formation associated with sudden cooling [14, 29].

The total heat exposure duration was around 7.5 hours; however, duration of specimen exposure was considered as 4 hours; the remaining 3.5 hours were at temperatures less than 200°C which is negligible since no further changes have been previously reported to occur [16,18].

Analysis

The analysis of trauma was approached in a step-by-step manner to ensure adequate prioritization of variables (Table 1). The approach was initially morphological and macroscopic whereby all trauma-associated defects were documented and photographed before and after burning and compared to those observed in the control samples as well as those previously reported in the literature [24, 58]. Several features were examined and documented as listed in Table 2, such as overall morphology of the injury and a description of the fractured edges.

3. Results

Control Samples: Thermal Alteration Characteristics in the Absence of Trauma

Table 3 presents all morphological heat defects observed in the control samples, illustrated in Figure 6. All samples were calcined with the characteristic colour a presented some degree of fragmentation (the images observed in Figure 6 are after reconstruction). Specimen CS 3 was the only specimen which was fully reconstructed due to the large size of the produced fragments. The most substantial degree of fragmentation in terms of the larger number of fractures and fragments produced, was observed in CS 4.

With the exception of splintering which was absent in CS3, the samples displayed all types of heat defects which have been reported in previously published burned bone experimental research and case studies. However, potential for misclassification of heat-induced fragmentation as blunt trauma exists, as can be observed in two of the control specimens (CS2 and CS4) which present wastage similar to that associated with both sharp force trauma and blunt force trauma. Whilst CS 1 did present wastage due to the loss of several small fragments, the morphology of the wastage sites can be clearly classified as heat-induced rather than mechanically-induced trauma.

The observed patterns of thermal trauma in the control specimens are in accordance with published research [24,49]. The patterns as a result of burning observed in the control group differed from those observed in the BFT and SFT specimens with regard to pattern morphology and the number of fractures. The heat fractures in the control specimens were of substantial depth with the majority penetrating the entire cortex, sharp and well-defined, particularly the longitudinal ones; their type and morphology correlate with previous studies which also utilized ‘wet’ bone [12,29].

Mechanical Trauma Signatures Pre-Burning

Overall, the morphological defects observed in the sharp force trauma samples were very similar (Table 4A and Fig.7). SFT 1-4, 6 and 7 presented defects typical of incisions: narrow width, superficial/medium depth, minimal/no wastage, absence of hinging and fracture lines. All incisions were V-shaped in cross-section, some of which were associated with raised edges (either on one side of the incision or on both sides) and/or peeling. Unilateral raised-edge morphology was observed in SFT 2 and 7 (Fig.8) while bilateral raised edge morphology was present in SFT 3 and 4, the former also exhibiting peeling (Fig.9). The SFT 5 incision was deeper and associated with hinging and an incomplete transverse fracture line on the posterior half of the bone shaft (Fig.10).

A similar damage pattern was also observed in the blunt trauma samples, whereby the majority sustained complete fractures (Table 4B and Fig.11). BFT 1, 3, 4 and 5 fractures were complete and associated with varying degrees of comminution whilst BFT 7 displayed a complete, simple fracture (Figs.12,13). In contrast, fractures in BFT 2 and 6 (Fig.14) were incomplete and associated with a ‘compression fracture’-like effect at impact site (also noted in BFT 3). Irrespective of fracture type, all fracture ends exhibited a regular, jagged/sharp outline with smooth surface morphology. Secondary or radiating ‘wet’ bone fractures were observed in all specimens and could be traced to a common origin (i.e. impact site), with the majority reaching the medullary cavity. Edge morphology and fracture angle originating from impact site were sharp, with a clearly defined and regular outline and angled relatively parallel to the long axis of the bone.

Mechanical Trauma Signatures Post-Burning

The sharp trauma incision sites were enhanced after thermal alteration and could be observed more clearly and in the specific cases of SFT 1 and 6 specimens the incision depths were exacerbated (Fig.7). Post-burning fragmentation, whether associated to the incision itself or as a result of heat was only noted in SFT 2, 4, 5, and 7. At incision sites, longitudinal and transverse heat fractures were the predominant types of substantial depth (Table 5), the latter producing complete separation of SFT 2 (Fig.15). Morphologically, the fractures exhibited an irregular appearance of overall outline, even and smooth edge surfaces and were angled either parallel to the long axis of the bone or were relatively oblique. Superficial fractures (i.e. they did not penetrate the cortex) were also noted, radiating from larger longitudinal fractures. Step fractures were only observed in SFT 3 and 5; in the former, this resulted in the production of a large fragment whilst in the latter, complete separation at incision site had occurred. Curved transverse fractures were observed on the posterior surfaces of SFT 1 and 3, close to the epiphyseal regions. With the exception of some remnants of raised-edge morphology in SFT 3, no other similar characteristic survived (Figs.16). However, the incision morphology of SFT 7 does indicate the presence of unilateral raised-edge morphology (Fig.17).

With regard to blunt trauma (Fig.11), outline sharpness was lost and surface morphology became rough in appearance, with no discernible regularity and associated with small projections (Fig.18). Except the step fractures observed only in BFT 5 and 6, all expected fracture types were observed and documented (Table 6). These were also irregular in outline with even and smooth surface morphology and were angled either parallel to the long axis of the bone or were relatively oblique. The greatest damage to overall bone integrity resulted from longitudinal fractures, the majority penetrating through the cortex. Curved transverse and patina fractures were superficial, with both types being present only at or in close proximity to the epiphyses. Fissures as described in the sharp force trauma specimens were also observed;

transverse fissures radiated from longitudinal ones and were deeper and longer. A unique pattern was observed in BFT 1, 2, 4-6 whereby a combination of transverse and longitudinal fractures created a ‘cross’ pattern (Fig.19).

The pre-existing fragmentation was only exacerbated in the samples with ‘compression-like’ fractures (i.e. resulting from a crushing action), namely BFT 2, 3 and 6. Larger fragments from the remaining specimens were preserved intact; whilst impact site fragments from sample 6 were lost (turned to ash); in comparison those from BFT 2 were recovered in a good enough condition for reconstruction. Qualitatively, heat-induced fragmentation was minimal, presenting as small chips of bone, splinter-like in morphology and originated from the fracture ends of all specimens (i.e. splintering effect) (Fig.20). Therefore, as expected, the overall heat defect and fracture patterns noted in the control samples were different from those observed in the trauma samples. Furthermore, the trauma samples did not present any heat-induced changes which significantly altered the mechanical trauma signatures. The latter were encountered in CS 2 and 4 (Fig.11,21): the defects had a rough appearance but smoothness and morphological regularity were still present and could be observed more clearly in comparison with the blunt trauma defects.

4. Discussion

The present study examined the degree to which concealment of sharp and blunt force trauma can be achieved by thermal alteration, taking into account homicide cases and the involvement of forensic anthropological expertise. The results have shown that signatures associated with sharp and blunt force trauma were not entirely masked by heat exposure and that there is potential for future standardization of fracture analysis in burnt bone given further experimentation of this nature. In the literature, perimortem trauma is exacerbated by heat [59-61] whereby pre-existing fracture lines radiating from impact points extend further along the bone shaft and increase in depth. However, in these studies, existing fracture lines prior to burning were notably different from heat fractures [12,29] which were sharp, well-defined and the majority penetrating the cortex, particularly the longitudinal ones. Based on these features, it has been possible to ‘trace’ the origin of the mechanical trauma impact [49,62,63] and distinguish them from post-burning damage. This is an aspect worth mentioning because a higher degree of damage was observed when the ceramic tiles within the furnace collapsed during the heating of specimens CS 2 and 4 resulting in further breakage, although this did not affect the overall fracture pattern. Whilst this is a limitation with respect to the change in position (i.e. ‘movement’) in relation to the fire, such damage is expected to be a common find in a forensic fire scenario, especially when taking into consideration any further damage sustained during the recovery and transportation of the remains. Thus, heat-related fracture patterns will not be obscured by post-cremation breakage and the latter only occurs along pre-existing penetrating heat fracture lines, exacerbates superficial fracture lines and originates from point of impact. In addition, fragments associated with comminuted fractures were all still recovered in their original shape. This illustrates the importance of laboratory conditions as testing environments: in an open-fire set-up, it is very likely that further fragmentation would have led to the omission of many fragments, thereby providing false data regarding percentage of successful recovery.

The specimen positioning and epiphyseal removal prior to burning are two factors which could have influenced heat fracture patterns in the experimental specimens. Hence, it is not possible to conclude with certainty whether the penetrating longitudinal fractures which extend to the cut ends in the SFT specimens are: a result of direct exposure to heat of the epiphyses or whether they represent an exacerbation of microscopic fractures produced by mechanical trauma or whether they are an indication of the type and severity of the mechanical trauma. In addition, the control and SFT specimens also exhibited secondary fractures of a more superficial depth at perpendicular angles to the primary ones. Since these were absent in the BFT samples, it suggests that the formation of these superficial secondary fractures in the SFT and control specimens is a means by which additional stress caused by heat accumulation within the cortex is alleviated. The influence of these heat stresses were eliminated in the BFT samples because the overall mechanical trauma damage was much more extensive and altered the effect of the heat-induced stresses along the bone shaft. As such, no superficial secondary fractures were produced at a macroscopic level. It was also interesting to note that fractures normally associated with fleshed remains were present. A rationale often presented in previous research attributes this find to uneven musculature contraction forces produced along the bone as the muscle shrink and 'pull' at their points of origin. This is debatable [13] and certainly not applicable herein because trauma samples were sawed off at their proximal and distal ends and defleshed.

Nevertheless, potential for evidence destruction exists, as exemplified by the obliteration of raised-edge morphology in the sharp trauma samples. Similarly, the severity of longitudinal heat fractures in both trauma types has the potential to destroy incision morphology. However, this study has demonstrated that the impact of these aspects can be minimized if appropriate recovery and handling methods are exercised.

5. Conclusions

This study, designed as a pilot to be followed by further experiments, has demonstrated that perimortem mechanical trauma induced by sharp or blunt force can be distinguished from thermal trauma. It has also emphasized that standardization of heat-induced fractures in skeletal remains evidencing perimortem trauma is possible. Hopefully, this study will encourage other researchers to further investigate this approach quantitatively and build towards a standardized experimental protocol for understanding and tackling analysis of burnt remains in a more robust manner. The reconstruction and analysis of the skeletal material utilized herein have been greatly facilitated by controlled and careful recovery and handling of the remains in an experimental setting; thus further demonstrating the need for a forensic anthropologist and/or archaeologist to be involved in recovery procedures at the fire scene. Knowledge of the location, position, orientation and condition of the remains and any associated evidence will facilitate both the reconstruction of a biological profile as well as assisting in the reconstruction of the events and circumstances surrounding death.

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References

[1] V.N. Ambade, H.V. Godbole, Comparison of wound patterns in homicide by sharp and blunt force, Forensic Sci. Int. 156 (2-3) (2006) 166-170.

[2] T.W. Fenton, J.L. deLong, R.C. Haut, Punched with a fist: the etiology of a fatal depressed cranial fracture, J. Forensic Sci. 48 (2) (2003) 1-5.

[3] Y. Delannoy, A. Becart, T. Colard, R. Delille, G. Tournel, V. Hedouin, D. Gosset, Skull wounds linked with blunt trauma (hammer example): A report of two depressed skull fractures – elements of biomechanical explanation, Leg. Med. 14 (5) (2012) 258-262.

[4] L.C. Smitherman, Missed diagnosis of an infant with a skull fracture, Clin. Paediatr. 50 (3) (2011) 259-261.

[5] D. Bury, N. Langlois, R.W. Byard, Animal-related fatalities – Part I: Characteristic autopsy findings and variable causes of death associated with blunt and sharp trauma, J. Forensic Sci. 57 (2) (2012) 370-374

[6] G. Berman, Knife Crime Statistics – House of Commons Standard Note SN/SG/4304. 2012.[online]. House of Commons. Available from <http://www.parliament.uk/briefing-papers/SN04304.pdf>. Accessed 12 August 2015.

[7] Fanton, L., Jdeed, K., Coartet-Tilhet, S. and Malicier, D. 2006. Criminal burning. Forensic Sci. Int. 158(2-3):87-93.

[8] J.A. Bytheway, N.C. Larison, A.H. Ross, Recognition of atypical burn patterns and pre-cremation blunt force trauma observed on human remains in two forensic cases in the United States, Anthropol. 2 (5) (2014) 1-6.

[9] V. Panaitescu, M. Rosu, Problems of forensic anthropological identification of carbonized human remains, Rom. Soc. Leg. Med. 15 (1) (2007) 39-44.

[10] D.H. Ubelaker, D.W. Owsley, M. M. Houck, E. Craig, W. Grant, T. , Woltanski, R. Fram, K. Sandness, N. Peerwani, The role of forensic anthropology in the recovery and analysis of Branch Davidian compound victims: recovery procedures and characteristics of the victims, J. Forensic Sci. 40 (3) (1995) 335-340.

[11] E.J. Pope, O.C. Smith, Identification of traumatic injury in burned cranial bone: an experimental approach, J. Forensic Sci. 49 (3) (2004) 1-10.

[12] D. Goncalves, The reliability of osteometric techniques for sex determination of burned human skeletal remains, Homo 62 (2011) 351-358.

[13] T.J.U. Thompson, Heat-induced dimensional changes in bone and their consequences for forensic anthropology, J. Forensic Sci. 50 (5) (2005) 1-8.

[14] B. Bradtmiller, J.E. Buikstra, 1984. Effects of burning on human bone microstructure: a preliminary study, J. Forensic Sci. 29 (2) (1984) 535-540.

[15] R. Nelson, R. 1992, A microscopic comparison of fresh and burned bone, J. Forensic Sci., 37 (4) (1992) 1055-1060.

[16] G. Piga, T.J.U. Thompson, A. Malgosa, S. Enzo, 2009. The potential of X-ray Diffraction in the analysis of burned remains from forensic contexts, J. Forensic Sci. 54 (3) (2009) 534-539.

[17] K.D. Rogers, P. Daniels, An X-ray diffraction study of the effects of heat treatment on bone mineral structure, Biomaterials, 23 (12) (2002) 2577-2585.

[18] J.L. Holden, P.P. Phakey, J.G. Clement, Scanning electron microscope observations of incinerated human femoral bone: a case study, Forensic Sci. Int. 74 (1-2) (1995a) 17-28.

[19] G. Quatrehomme, M. Bolla, M. Muller, J.-P. Rocca, G. Grevin, P. Bailet, A. Ollier, Experimental single controlled study of burned bones: Contribution of scanning electron microscopy, J. Forensic Sci. 43 (2) (1998) 417-422.

[20] H.E.C. Koon, R.A. Nicholson, M.J. Collins, A practical approach to the identification of low temperature heated bone using TEM, J. Archaeol. Sci. 30 (11) (2003) 1393-1399.

[21] T.J.U. Thompson, M. Gauthier, M. Islam, The application of a new method of Fourier Transform Infrared Spectroscopy to the analysis of burned bone, J. Archaeol. Sci. 36 (3) (2009) 910-914.

[22] C. Snoeck, J.A. Lee-Thorp, R.J. Schulting, From bone to ash: compositional and structural changes in burned modern and archaeological bone, Palaeogeogr. Palaeoclimatol. Palaeoecol. 416 (2014) 55-68.

[23] D.M. Glassman, M.C. Rodney, Standardization model for describing the extent of burn injury to human remains, J. Forensic Sci. 41(1) (1996) 152-154.

[24] S.A. Symes, C.W. Rainwater, E.N. Chapman, D.R. Gipson, A. Piper, Patterned thermal destruction of human remains in a forensic setting. In: CW. Schmidt and S.A. Symes (eds.),The Analysis of Burned Human Remains, London, Academic Press, 2008, pp. 15-54.

[25] A.R. Tumer, R. Akcan, E. Karacaoglu, A. Balseven-Odabasi, A. Keten, C. Kanburoglu, M. Unal, A.H. Dinc, Postmortem burning of the corpses following homicide, J. Forensic Leg. Med. 19 (4) (2012) 223-228.

[26] A.M. Christensen, Experiments in the combustibility of the human body, J. Forensic Sci. 47 (3) (2002) 466-470.

[27] V. Alunni, G. Grevin, L. Buchet, Y. Gaillard, G. Quatrehomme, An amazing case of fatal self-immolation, Forensic Sci. Int. 244 (2014) e30-33.

[28] M. Bohnert, T. Rost, M. Faller-Marquardt, D. Ropohl, S. Pollak, Fractures of the base of the skull in charred bodies – post-mortem heat injuries or signs of mechanical traumatisation?, Forensic Sci. Int. 87 (1) (1997) 55-62.

[29] M. Bohnert, T. Rost, S. Pollak, The degree of destruction of human bodies in relation to the duration of the fire, Forensic Sci. Int. 95 (1) (1998) 11-21.

[30] W.M. Bass, R.L. Jantz, Cremation weights in East Tennessee, J. Forensic Sci. 49 (5) (2004) 1-4.

[31] K.A. Murray, J.C. Rose, The analysis of cremains: a case study involving the inappropriate disposal of mortuary remains, J. Forensic Sci. 38 (1) (1993) 98-103.

[32] T.G. Baumer, N.V. Passalacqua, B.J. Powell, W.N. Newberry, T.W. Fenton, R.C. Haut, Age-dependent fracture characteristics of rigid and compliant surface impacts on the infant skull – a porcine model, J. Forensic Sci. 55 (4) (2010) 993-997.

[33] N. Glaser, B.P. Kneubuehl, S. Zuber, S. Axmann, T. Ketterer, M.J. Thali, S.A. Bolliger, Biomechanical examination of blunt trauma due to baseball bat blows to the head, J. Forensic Biomech. 2 (2011) 1-5.

[34] Z. Asgharpour, D. Baumgartner, R. Willinger, M. Graw, S. Peldschus, The validation and application of a finite element human head model for frontal skull fracture analysis, J. Mech. Behav. Biomed. Mater. 33 (2014) 16-23.

[35] J. Motherway, M.C. Doorly, M. Curtis, M.D. Gilchrist, Head impact biomechanics simulations: a forensic tool for reconstructing head injury?, Leg. Med. 11 (1) (2009) S220-S222.

[36] A.L. Bradley, M.V. Swain, J.N. Waddell, R. Das, J. Athens, J.A. Kieser, A comparison between rib fracture patterns in peri- and postmortem compressive injury in a piglet model, J. Mech. Behav. Biomed. Mater. 33 (2014) 67-75.

[37] C. Cattaneo, E. Marinelli, A. Di Giancamillo, M. Di Giancamillo, O. Travetti, L. Vigano, P. Poppa, D. Porta, A. Gentilomo, M. Grandi, Sensitivity of autopsy and radiological examination in detecting bone fractures in an animal model: implications for the assessment of fatal child physical abuse, Forensic Sci. Int. 164 (2-3) (2006) 131-137.

[38] R.R. Adharapurapu, F. Jiang, K.S. Vecchio, Dynamic fracture of bovine bone, Mater. Sci. Eng. C Mater. Biol. Appl. 26 (8) (2006) 1325-1332.

[39] B. Karger, K. Teige, M. Fuchs, B. Brinkmann, Was the pedestrian hit in an erect position being run over?, Forensic Sci. Int. 119 (2) (2001) 217-220.

[40] D. Richter, M.P. Hahn, P.A.W. Ostermann, A. Ekkernkamp, G. Muhr, Vertical deceleration injuries: a comparative study of the injury patterns of 101 patients after accidental and intentional high falls, Injury, 27 (9) (1996) 655-659.

[41] I. Horsfall, C. Watson, S. Champion, P. Prosser, T. Ringrose, The effect of knife handle shape on stabbing performance, Appl. Ergon. 36 (4) (2005) 505-511.

[42] D.J. Carr, A. Wainwright, Variability of simulants used in recreating stab events, Forensic Sci. Int. 210 (1) (2011) 42-46.

[43] C. Crowder, C.W. Rainwater, J.S. Fridie, Microscopic analysis of sharp force trauma in bone and cartilage: A validation study, J. Forensic Sci. 58 (5) (2013) 1119-1126.

[44] D. Gibelli, D. Mazzarelli, D. Porta, A. Rizzi, C. Cattaneo, Detection of metal residues on bone using SEM-EDS-Part II: Sharp force injury, Forensic Sci. Int. 223 (1) (2012) 87-90.

[45] B.K. Tucker, D.L. Hutchinson, M.F.G. Ghilliland, T.M. Charles, H.J. Daniel, L.D. Wolfe, Microscopic characteristics of hacking trauma, J. Forensic Sci. 46 (2) (2001) 234-240.

[46] T.J.U. Thompson, J. Inglis, Differentiation of serrated and non-serrated blades from stab marks in bone, Int. J. Leg. Med. 123 (2) (2009) 129-135.

[47] A.M. Croft, R. Ferllini, Macroscopic characteristics of screwdriver trauma, J. Forensic Sci. 52 (6) (2007) 1243-1251.

[48] S. De Gruchy, T.L. Rogers, Identifying chop marks on cremated bone: a preliminary study, J. Forensic Sci. 47 (5) (2002) 1-4.

[49] N.P. Herrmann, J.L. Bennett, The differentiation of traumatic and heat-related fractures in burned bone, J. Forensic Sci. 44 (3) (1999) 461-469.

[50] R. Hausmann, P. Betz, Thermally-induced entrance wound-like defect of the skull, Forensic Sci. Int. 128 (3) (2002) 159-161.

[51] C. Cattaneo, S. DiMartino, S. Scali, O.E. Craig, M. Grandi, R.J. Sokol, Determining the human origin of fragments of burnt bone: a comparative study of histological, immunological and DNA techniques, Forensic Sci. Int. 102 (2-3) (1999) 181-191.

[52] D. Ruscillo, (Ed.), Recent Advances in Ageing and Sexing Animal Bones, Oxford, Oxbow Books, 2015.

[53] P. Shipman, G. Foster, M. Schoeninger, Burnt bones and teeth: an experimental study of colour, morphology, crystal structure and shrinkage, J. Archaeol Sci. 11 (4) (1984) 307-325.

[54] T.J.U. Thompson, J.A. Chudek, A novel approach to the visualization of heat-induced structural change in bone, Sci. Justice, 47 (2) (2007) 99-104.

[55] J.H. Humphrey, D.L. Hutchinson, Macroscopic characteristics of hacking trauma, J. Forensic Sci. 46 (2) (2001) 228-233.

[56] K.S. Lynn, S.I. Fairgrieve, Macroscopic analysis of axe and hatchet trauma in fleshed and defleshed mammalian long bones, J. Forensic Sci. 54 (4) (2009) 786-792.

[57] E.J. Bartelink, J.M. Wiersema, R.S. Demaree, Quantitative analysis of sharp-force trauma: An application of scanning electron microscopy in forensic anthropology, J. Forensic Sci. 46 (6) (2001) 1288-1293.

[58] M.Y. Iscan, M. Steyn, The Human Skeleton in Forensic Medicine, Charles C Thomas, Springfield, 2013.

[59] M. Hanson, R. Cain, Examining histology to identify burned bone, J. Archaeol. Sci. 34 (11) (2007) 1902-1913.

[60] G. Grevin, P. Bailet G, Quatrehomme, A. Ollier, Anatomical reconstruction of fragments of burned human bones: a necessary means for forensic identification, Forensic Sci. Int. 96 (2-3) (1998) 129-134.

[61] F. Collini, A. Adamasi, A. Mazzucchi, D. Porta, V.L. Regazzola, P. Garofalo, A. Di Blasio, C. Cattaneo, The erratic behaviour of lesions in burnt bone, J. Forensic Sci. 60 (5) (2015) 1290-1294.

[62] P. Poppa, D. Porta, G. Gibelli, A. Mazzucchi, A. Brandone, M. Grandi, C. Cattaneo, Detection of blunt, sharp force and gunshot lesions on burnt remains: a cautionary note, Am J Forensic Med Pathol 32 (3) (2011) 275-279.

[63] S.M. Marciniak, A preliminary assessment of the identification of saw marks on burned bone, J Forensic Sci. 54(4) (2009) 779-785.

Figure 1 – Anterior view of the sharp impactor

Figure 2 – Anterior view of the blunt impactor

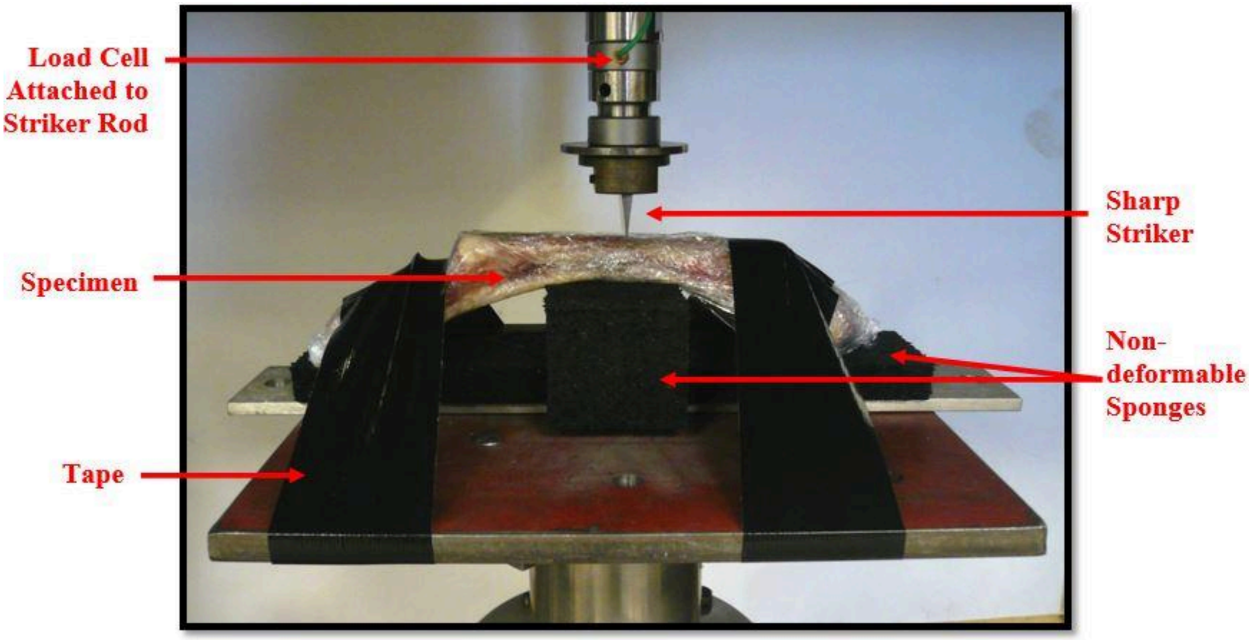

Figure 3 – Lateral view of the sharp force trauma specimen arrangement during impact

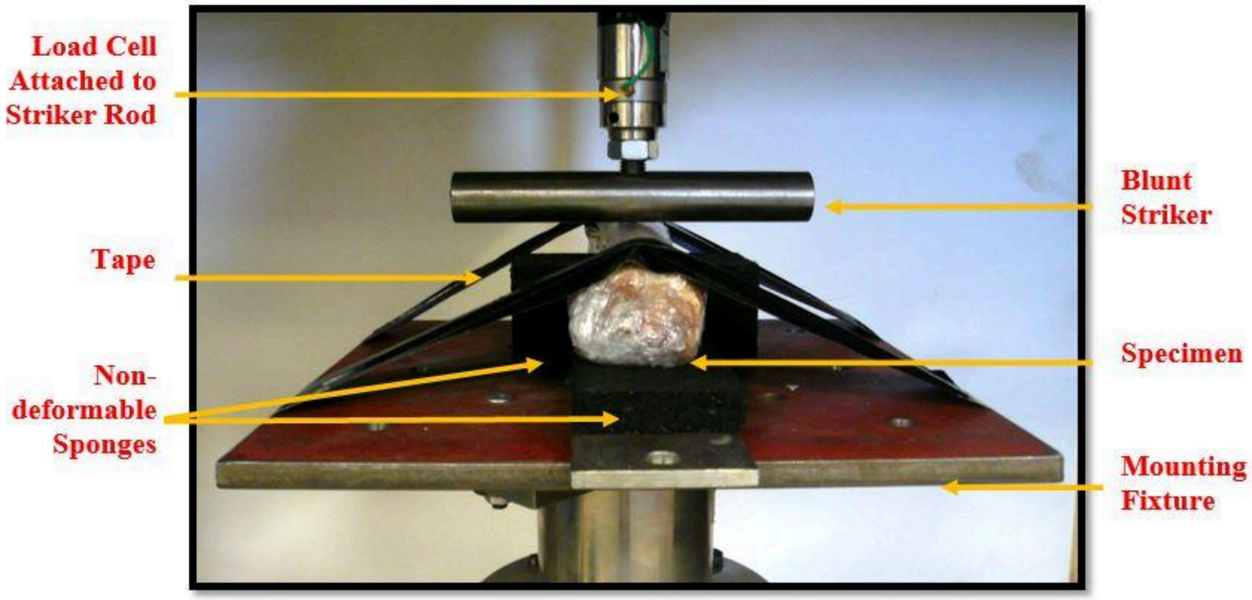

Figure 4 – Anterior view of the blunt force trauma specimen arrangement during impact

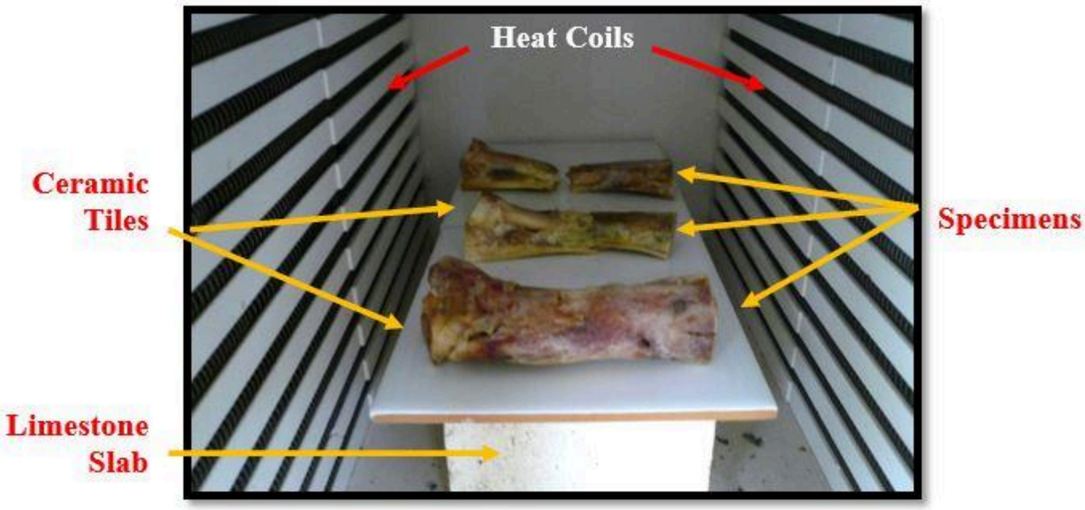

Figure 5 – Example of Specimen Positioning Inside Cremation Chamber

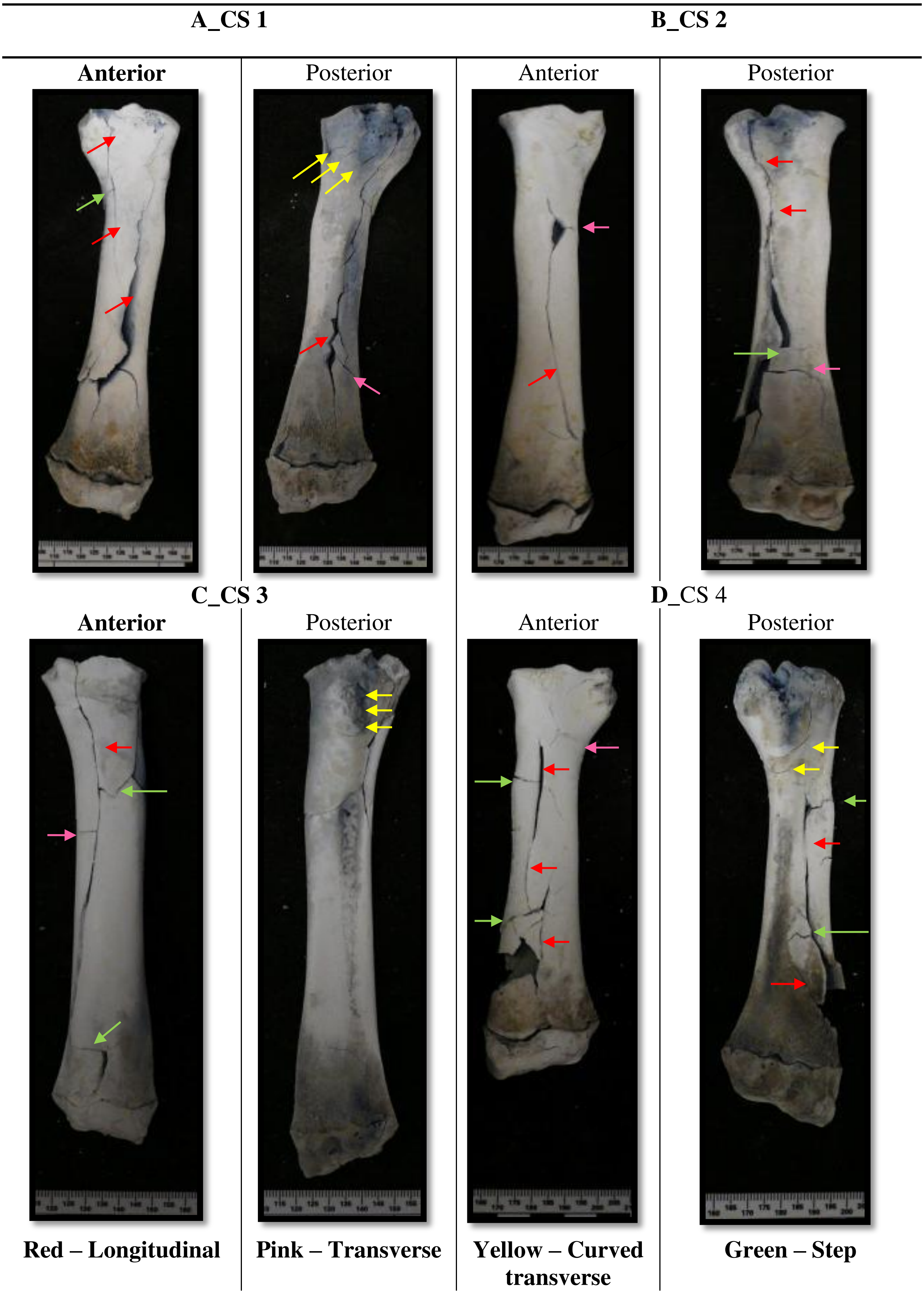

Figure 6 – Heat Fracture Patterns in the Control Specimens

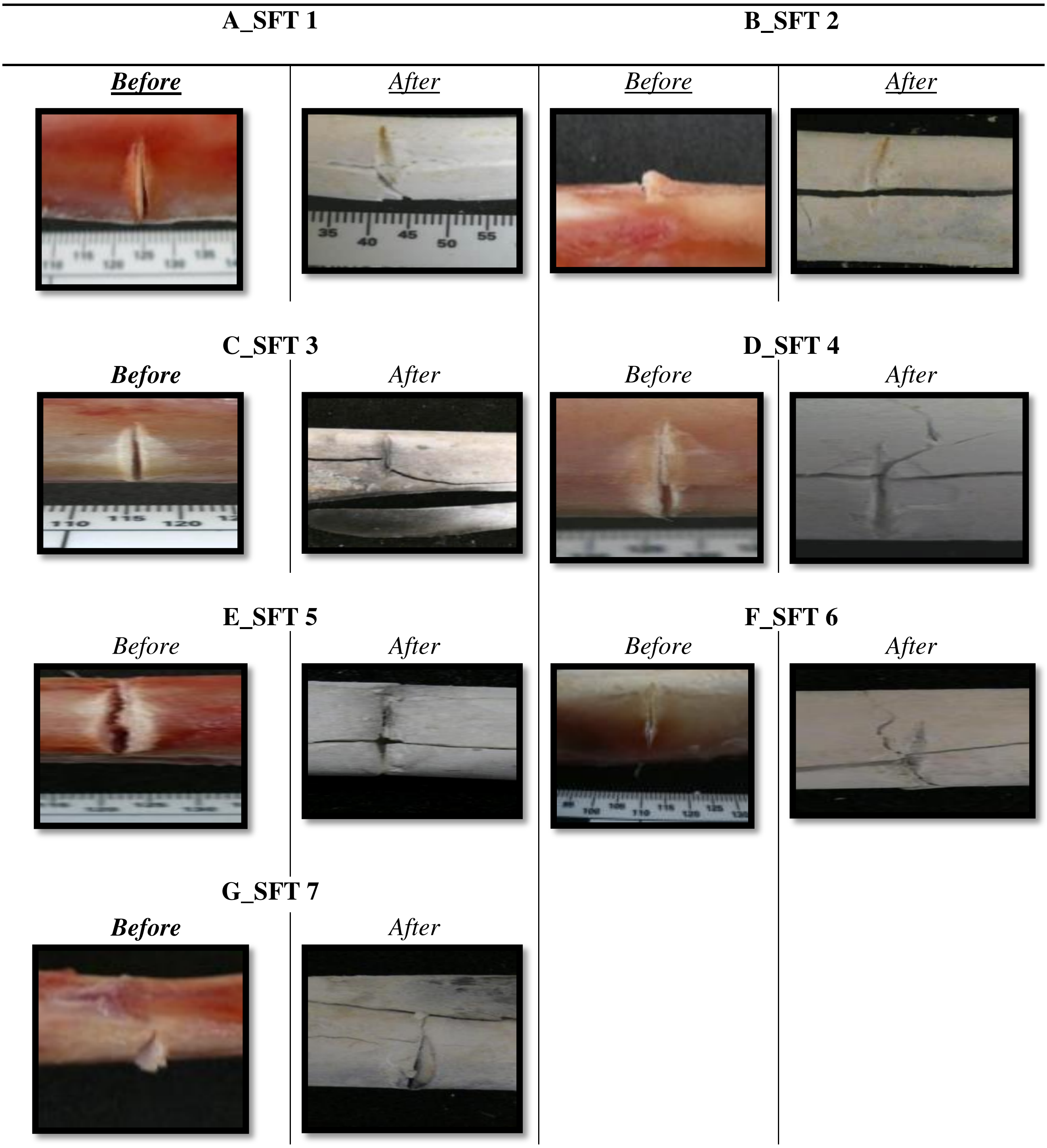

Figure 7 – Sharp Force Trauma Before and After Thermal Alteration: A Comparison

Figure 8 – Example of large bone spur on the right wall of the incision in SFT 2

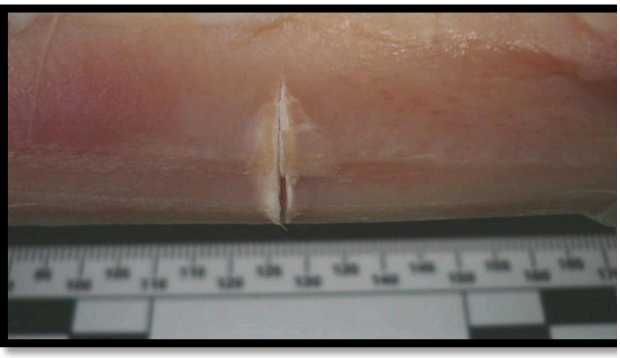

Figure 9 – Example of raised-edge morphology at incision site and peeling (upper right side of incision) in SFT 4

Figure 10 – Sample SFT 5 exhibiting deep incision

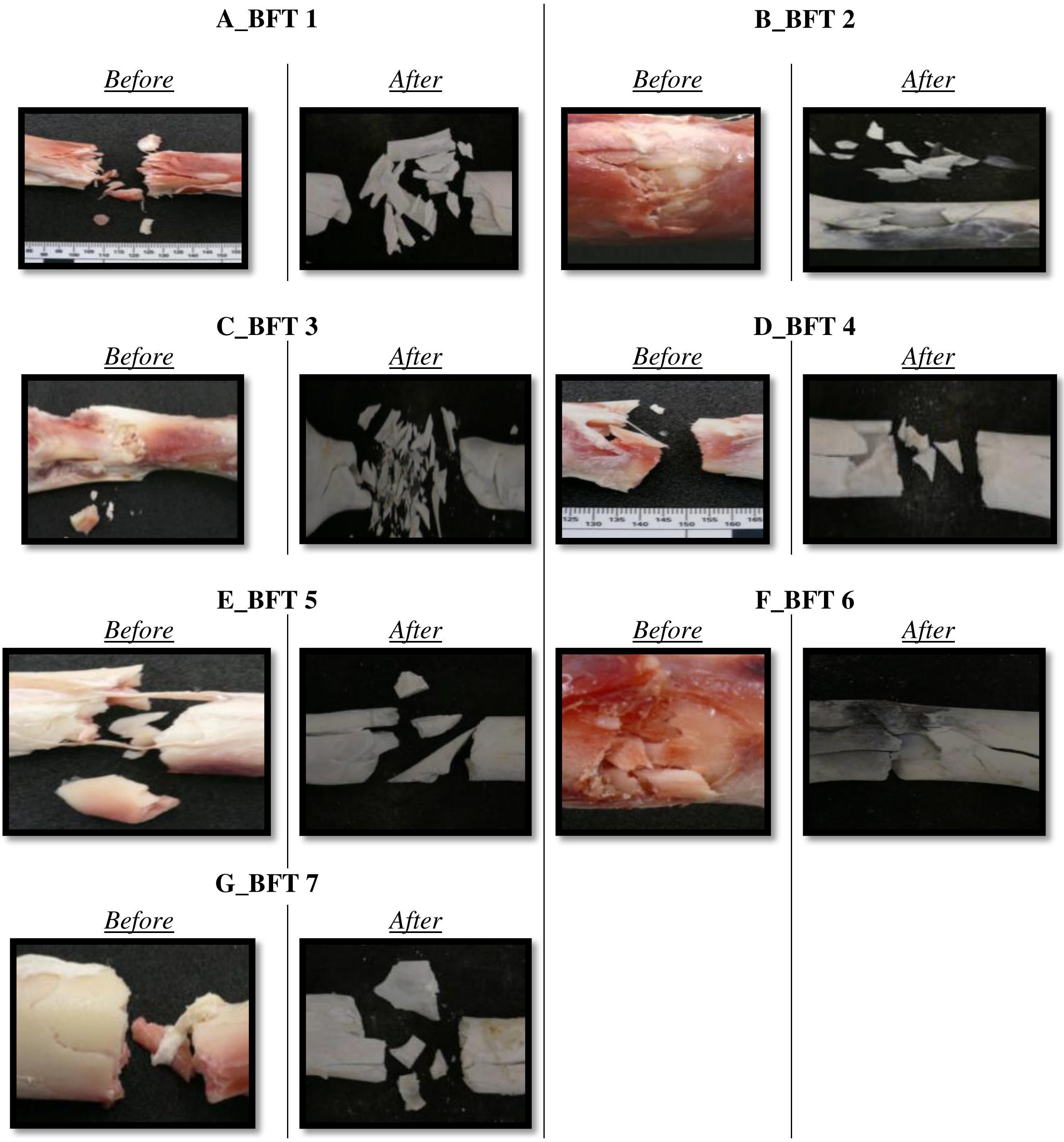

Figure 11 – Blunt Force Trauma Before and After Thermal Alteration: A Comparison

Figure 12 – Example of complete fracture in BFT 1

Figure 13 – Complete, simple fracture in BFT 7

Figure 14 – Example of crushing effect in BFT 6

Figure 15 – Illustration of complete separation of SFT 2

Figure 16 – Raised-edge morphology apparent in SFT 3

Figure 17 – Incision morphology of SFT 7 indicating the presence of a bone spur prior to heat exposure

Figure 18 – Example of blunt outline of the perimortem fracture in BFT 5

Figure 19 – Example of cross-pattern in BFT 1

Figure 20 – Example of heat-induced fragmentation in BFT 1

Figure 21 – Example of splintering effect in BFT 7

Table 1

Independent and Dependent Variables

Independent variables	Dependent Variables
Specimens	
- Species - Age - Skeletal element	Types of heat fractures
Mechanical Trauma	Differentiation between heat and mechanical trauma fractures
- Specimen positioning and fixation - Impact velocity, mass and force - Region and angle of strike	Degree of mechanical trauma concealment
Thermal Trauma	
- Type of furnace - Positioning of specimens - Starting temperature - Peak temperature - Duration	Occurrence of mechanical trauma-mimicking heat artefacts

Table 2

Pre-burning and post-burning variables examined

Blunt Trauma	Sharp Trauma	Thermal Trauma
Fracture category	Fracture category	Fracture type
Fragmentation severity	Fracture outline	Fracture morphology
Fracture outline	Wastage	Fracture outline
Fracture surface morphology	Secondary fractures	Fracture angle
Secondary factures		Delamination
		Splintering

Table 3

Types of thermal alteration defects observed in the control specimens

Type of Defect	Specimen (CS)			
	1	2	3	4
Longitudinal fracture	√	√	√	√
Step fracture	√	√	√	√
Transverse fracture	√	√	√	√
Curved transverse fracture	√	√	√	√
*Patina fractures	√	√	√	√
Splintering	√	√	X	√

**Delamination	√	√	√	√

*present at epiphyseal regions

** present at and around the epiphyseal regions

√ – present

X – absent

Table 4

Summary of BFT and SFT sample characteristics pre- and post-burning

Trauma type	Pre-burning	Post-Burning
A. Sharp Force		
Fracture category	incisions of superficial/medium depth deep incision in SFT 5	incisions in SFT 1-4, 6, 7 enhanced SFT 1 and 6 incision depths exacerbated but no change to overall pattern SFT 5 incision exacerbated and altered into a complete fracture
Fracture outline and morphology	V-shaped	V-shaped
Wastage	absent	present in SFT 2, 4, 5, 7; associated with the incision and/or with heat fractures
Secondary fractures	SFT 5: hinge and partial transverse fracture	SFT 5 secondary fractures exacerbated present in SFT 1-4, 6, 7 as heat fractures and associated with the incision sites and/or specimen extremities heat fractures in SFT 2 and 5 resulted in complete separation at incision site
Peeling	SFT 3	absent in all specimens
Raised-edge morphology	SFT 3, 4	SFT 3
Bone spurs	SFT 2, 7	SFT 7
B. Blunt Force		
Fracture category	complete: BFT 1, 3-5, 7 (BFT 3 impact site associated with compression-like fracture) incomplete: BFT 2, 6 (associated with compression-like fracture at impact)	general pattern of the complete fractures unchanged overall pattern in BFT 6 altered due to 'ashing' of smaller fragments
Degree of fragmentation	slight to moderate	exacerbated in BFT 2, 3, 6
Fracture type	transverse; irregular	general pattern unchanged
Fracture outline and surface morphology	sharp; smooth	blunt; irregular/rough to the touch and appearance
Secondary Fractures	present in all specimens	Pre-existing fractures exacerbated by heat fractures; Heat-induced cross-shaped pattern observed in BFT 1, 2, 4-6

Table 5

Heat-induced defects in the sharp force trauma samples

Fracture Type	Specimen (SFT)						
	1	2	3	4	5	6	7
Longitudinal	√	√	√	√	√	√	√
Step	X	X	√	X	√	X	X
Transverse	√	√	√	√	√	√	√
Curved transverse	√	X	√	X	X	X	X
Splintering	X	√	X	√	√	X	√

√ – present

X – absent

Table 6

Heat-induced defects in the blunt force trauma samples

Type of defect	Specimen (BFT)						
	1	2	3	4	5	6	7
Longitudinal fracture	√	√	√	√	√	√	√
Step fracture	X	X	X	X	√	√	X
Transverse Fracture	√	√	√	√	√	√	√
*Patina Fracture	√	√	√	√	√	√	√
Curved Transverse Fracture	√	√	√	√	√	√	√
Splintering	√	√	√	√	√	√	√

*present at epiphyses

√ – present

X – absent